

# PATENT SPECIFICATION

NO DRAWINGS

Inventors: RICHARD CHROMECEK, OTTO WICHTERLE, IVA GAVRILOVA  
MIROSLAV KUBIN and PAVEL SPACEK

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## COMPLETE SPECIFICATION

### Method for Manufacturing Macroporous Polymers

We, CESKOSLOVENSKA AKADEMIE VED, a Czechoslovak Corporation of No. 3 Narodni, Praha, 1, Czechoslovakia, do hereby declare the invention, for which we pray that a patent  
5 may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

It is known that copolymerization of styrene with divinyl benzene in presence of liquids dissolving said monomers but unable to dissolve the copolymer results in macroporous copolymers (copolymers with apparent porosity). Copolymerization of hydrophilic monomers  
10 such as ethylene glycol monomethacrylate with ethylene glycol bis - methacrylate in presence of more water than the copolymer can retain by swelling (e.g. 60% or more water) yielded also a spongy hydrogel with very fine capillary pores. The pores disappear, however, permanently if the spongy polymer is dried out, and cannot be renewed by new swelling: the polymer remains glassy and transparent or translucent, displaying no  
15 apparent porosity at all. This circumstance makes said hydrophilic spongy polymers unsuitable for different purposes where repeated sorption is required, such as for chromatography for filtration of non-aqueous liquids and similar. The manufacture of such spongy polymers was first disclosed by O. Wichterle and D. Lim in their patents, e.g. in the U.S. Patent Specifications No. 2,976,576 and 3,220,960.

An object of the present invention is to provide hydrophilic copolymers of the above mentioned kind having permanent macroporous structure. Another object of the invention is to manufacture hydrophilic macroporous copolymer structures in situ, inside of tubes or  
20 25 30 35 40

otherwise shaped supporting structures in order to obtain non-leaking sorption columns or similar devices.

The hydrophilic properties are advantageous for certain purposes, e.g. for separating polar and non-polar compounds, for making detectors for polar compounds in gas-analysis etc.

The method according to the invention consists in copolymerization a bifunctional hydrophilic unsaturated monomer such as glycol methacrylate or acrylate with a cross-linking agent soluble in the monomeric mixture, e.g. glycol bis - methacrylate or N,N' - methylenebis - methacryl amide in absence of any substantial amount of water or other polar solvents and in presence of a liquid which dissolves the monomers to a homogenous monomeric mixture but which does neither dissolve nor swell the copolymer thus formed.

Typical examples of such liquids are aromatic hydrocarbons such as benzene, toluene, xylene or similar. It is, however, possible to use with similar results also esters, chlorinated hydrocarbons, ethers, ketones, higher aliphatic alcohols, cyclo - aliphatic alcohols.

Suitable are also many macromolecular compounds soluble in the monomeric mixture, e.g. polyvinyl alcohol, silicone oils, polyesters, polyethyleneoxide and similar.

The macroporous hydrophilic polymers obtained in the above described way differ substantially from the spongy hydrogels known hitherto. Their pores are larger and do not disappear when the polymer is dried out. Thus, the material does not lose its sorption capacity when used repeatedly. The novel macroporous hydrophilic copolymers can be used e.g. as substrates for anchored liquid phase in gas-liquid chromatography, as inert  
45 50 55 60 65 70 75 80

substrate for catalysts, as sorption and/or filtration material, particularly in non-aqueous media etc.

By carrying out the copolymerization in a suitable mould or in a tube or in other supporting structure it is possible to create different ready-made sorptive systems having any desired shape and size and filling up uniformly the whole cross-section of the device. A sorption column made in this way has no dead space and is highly effective. There is no abrasion of the filling even after a very long service time, in contradistinction to usual granular loose fillings.

When adding some liquid capable of swelling the finished copolymer, it is possible to regulate the size and structure of pores and to adjust the properties of the copolymer to any desired special purpose. Such swelling agents are e.g. lower aliphatic alcohols (methanol, ethanol, propanol), allyl alcohol, tetrahydrofurfuryl alcohol, ethylene glycol, polyethylene glycols, homological glycols, glycol ethers, tetrahydrofurane, formamide, dimethylformamide, pyridine, dimethyl sulfoxide and others.

The monomers used for the purpose of the present invention may also contain ionogenic groups, or such groups may be introduced subsequently into the polymer. It is thus possible to add to a monomeric mixture, consisting mainly of a methacrylate or acrylate of a glycol or of another polyol, e.g. methacrylic or acrylic acid, or maleic anhydride, itaconic acid, an ester or a salt of ethylenesulphonic acid, styrenesulphonic acid, or dimethylacrylamide, which is subsequently reduced (e.g. with dialkoxysodium aluminium hydride  $\text{NaAlH}_2(\text{OCH}_2\text{CH}_2\text{OCH}_3)_2$ ) and then quarternized in usual way.

Most appropriate monomers for producing macroporous hydrophilic copolymers according to the invention are monomethacrylates and monoacrylates of ethyleneglycol, diethylene glycol or further ethylene glycol polycondensates, glycerol, pentaerythritol and other polyols. As cross-linking agents the corresponding glycol diesters of  $\alpha,\beta$ -unsaturated acids prove best. Glycerol trimethylacrylate or other unsaturated triesters can also be used.

In principle, any sufficiently stable cross-linking agent, having two or more polymerizable double bonds and sufficiently soluble in the monomeric mixture, may be used. It is to be understood, however, that the hydrophilic unsaturated monomer can be utilized together with any cross-linking agent which is sufficiently soluble in other components, and with a solvent for said monomers which does not swell the resulting copolymer. Further examples of suitable monomers are monomethacrylates or monoacrylates of glycerol, pentaerythritol, mannitol or other sugars.

The amount of the cross-linking agents may be chosen in broad limits, according to the

required properties of the product. When using only a slight amount of a cross-linking agent (e.g. less than 2 per cent), copolymers are obtained which swell in water and in polar solvents. A higher percentage of cross-linking agents leads to copolymers which are low swelling and tough. For special purposes it is possible to use long-chain cross-linking agents, e.g. dimethacrylates of polyethyleneglycols having an average molecular weight of 1500—3000. By appropriate combination of chain length of cross-linking agents, its molar fraction in relation to the monoolefinic monomer and percentage of the solvent causing the macroporosity it is possible to prepare a whole set of macroporous materials with various properties suitable for chromatography, filtration, sorption or any other special purpose.

The lowest amount of the liquid causing the building of macroporous structure depends on its character and simultaneously on the kind of monomer and the amount of the cross-linking agent used. When using aromatic hydrocarbons, the lowest effective amount of the solvent is about 20 per cent. The top limit is given by the required strength which decreases with increasing amount of the solvent.

If a lower percentage of the solvent than the minimal effective amount is added, only usual glassy, non-porous structures are obtained upon drying.

If the macroporous filling is not formed by copolymerization in situ, the polymerization can be carried out in a mould and the blocks thus obtained are either comminuted to grains and sieved or used as such.

If a column with homogeneous fixed filling of a macroporous hydrophilic polymer is to be manufactured, a glass or metal sheet tube of suitable size is filled with homogeneous solution of a hydrophilic mono-olefinic monomer, such as ethylene glycol monomethacrylate, with desired amount of a cross-linking agent such as ethylene glycol bis-methacrylate in solvent which does not swell the resulting cross-linked copolymer, e.g. in toluene. The solution is initiated with e.g. 0.3% of diisopropyl percarbonate and the solution is poured into the above mentioned tube. Polymerization is realized by heating the tube externally to about 60°C for one hour. Toluene is then washed out with an appropriate solvent such as anhydrous ethanol which, in turn, is displaced by ethylene glycol monomethylether. The latter is left in the column, forming the anchored liquid phase for gas-liquid chromatography.

If the amount of the solvent is comparatively low, i.e. 30—60%, the filling is self-supporting and there is no necessity to provide a bottom from porous glass or other filtration material.

Columns of macroporous hydrophilic

70

75

80

85

90

95

100

105

110

115

120

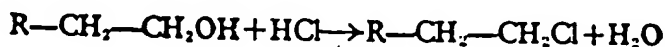
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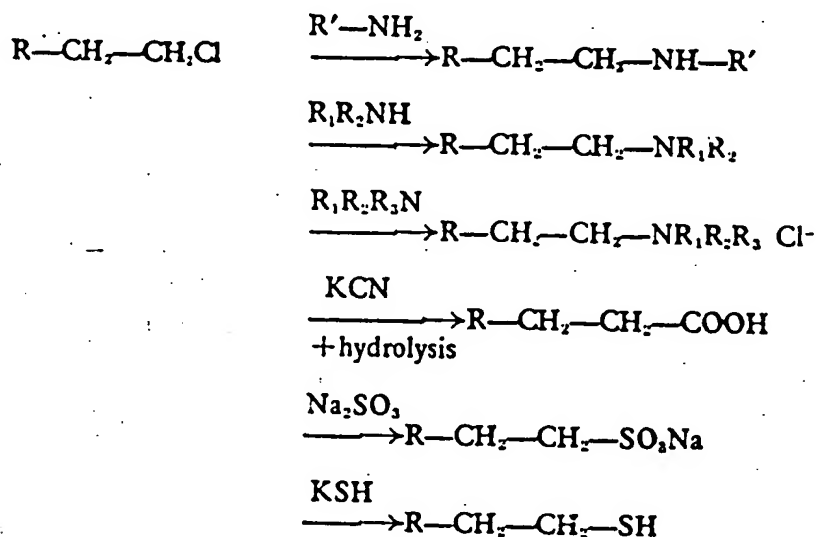
material made with a comparatively low percentage of solvent can be also prepared in form of rods, which are then provided with an appropriate jacket or mantle from plastics or metal sheet.

Finished macroporous hydrogels according to the invention can be also subsequently

modified by suitable chemical reactions. For instance macroporous hydrogels made by polymerizing ethylene glycol methacrylate can be reacted either with thionyl chloride or hydrogen chloride, whereby a polymeric chlorohydrine ester is obtained:



where R is the elementary unit of methacrylic acid. Polymeric chlorohydrine ester can be either used as such as carrier for chromatography in non-aqueous media, or can be used for different further reactions known per se according to the following diagram:



In similar manner it is possible to prepare further macroporous polymer derivatives such as thiocyanates, thiuronium salts, sorbents for humin acids and others.

Macroporous copolymers of the above described sort have thus various uses as chromatographical sorbents, ion exchanger skeletons, sorbents for various organic compounds (e.g. for isolation and separation of antibiotics), carriers for catalysts, materials for gel filtration. In comparison with usual materials such as polymers based on dextrene they have the advantage of stability in both acid and basic media. So e.g. macroporous glycol methacrylate polymer is not attacked at 20°C by hydrochloric acid or sodium lye in concentrations up to 20 per cent.

#### EXAMPLE 1

150 ml of toluene, 17.4 ml of ethyleneglycol - bis - methacrylate, 332 ml of ethyleneglycol monomethacrylate and 0.05 g of dibenzoyl peroxide are mixed together to a homogeneous solution which is then bubbled with pure nitrogen and polymerized at 50°C for 6 hours under nitrogen. Homogeneous macroporous material thus formed is comminuated to grains and toluene is removed either by drying at reduced pressure or by steam-distillation. The product can be divided

into several fractions by sieving and used as filling of sorption columns.

In similar way analogical copolymers based on diethylene glycol or triethylene glycol methacrylates with various cross-linking agents such as glycerol trimethacrylate can be prepared. Their porosity is changed by changing the percentage of toluene added.

#### EXAMPLE 2

150 ml of benzene, 20 ml of ethyleneglycol - bis - methacrylate, 350 ml of ethyleneglycol monomethacrylate and 0.08 g of diisopropyl percarbonate are thoroughly mixed together until a homogeneous solution is obtained. The solution is then poured into a poly - tetrafluoroethylene tube heated from outside to 60°C. After finished copolymerization benzene is displaced by anhydrous ethanol which is, finally, displaced by ethyleneglycol monomethyl - ether. The filled tube is suitable for gas-liquid chromatography.

#### EXAMPLE 3

In a cylindrical reactor provided with a stirrer there were dissolved 41.1 g of magnesium sulfate - heptahydrate and 110 g of water. Then a solution of 11.31 g of sodium hydroxide in 34.25 ml of water was added during 15 minutes while stirring. To the

suspension of 1.5% of magnesium hydroxide in the salt solution thus obtained 83.4 ml of monomeric mixture, consisting of 48.42 ml of ethyleneglycol monomethacrylate, 4.98 ml of ethylene - glycol - bis - methacrylate, 0.5 g of dibenzoyl peroxide and 25 ml of toluene was added while stirring. After 10 minutes of stirring at 25°C the temperature was increased to 60°C. During 2 hours strong spheres of macroporous copolymer were formed. The copolymerization was finished by a three-hours stirring at the same temperature. Thereafter magnesium hydroxide was dissolved by adding an about equivalent amount of hydrochloric acid, the suspension copolymer was filtered off, washed with water and dried. The size of the spheres could be easily controlled by changing the rotating speed of the stirring device and the amount of magnesium hydroxide. Smaller spheres are formed at higher amounts of magnesium hydroxide and increased rotational speed.

#### EXAMPLE 4

A mixture of 7.5 ml. of toluene, 6.005 ml of ethylene - glycol monomethacrylate, 1.495 ml of ethyleneglycol - bis - methacrylate and 0.1 g of dibenzoyl peroxide was poured into a 5.3 mm calibre glass tube with sealed bottom. The polymerization lasted 3 days at 28°C. The sealed bottom was then cut off and the column thus obtained was washed first with methanol and then with water. It was suitable as sorbent column for analytical purposes.

#### EXAMPLE 5

Macroporous polymer in form of a rod was made by pouring a mixture of 10.5 ml of toluene, 4.78 ml of ethylene - glycol - bis-methacrylate, 19.72 ml of ethyleneglycol monomethacrylate and 0.35 g of dibenzoyl peroxide into a mould prepared from wood-metal, using a test tube as patrix. The solution was bubbled with nitrogen and heated to 50°C for 5 hours. The metal was then melted off and its remainders were washed off with toluene at 100°C. The rod from macroporous polymer was then mechanically worked to the desired shape, toluene was washed out with methanol and the latter removed by evaporation in a stream of warm nitrogen sucked through the polymer.

#### EXAMPLE 6

Preparation of polymeric macroporous chlorhydrine ether. 78 g of the macroporous copolymer prepared according to Example 1 in the form of grains 0.2—0.5 mm diameter were suspended in 250 ml of thionylchloride and the suspension in 250 ml of thionyl - chloride and the suspension was boiled under reflux for 4 hours while stirring. Then 1 ml of anhydrous pyridine was added and the suspension was boiled for another 2 hours.

The surplus of thionylchloride was distilled off, the copolymer was washed with benzene and benzene was removed in boiling water. The yield was 80 g of chlorinated copolymer containing 21.5% of chlorine. The chlorhydrine copolymer was suitable for use as sorbent in non-aqueous liquids.

The chlorine content of the product depends on the cross-linking degree: In an analogous Example with but 2% of cross-linking agent the chlorine content amounted to 23% with 20% of cross-linking agent it was only 18.5%.

#### EXAMPLE 7

Amination of a polymeric chlorhydrine ether. 80 g of polymeric macroporous chlorhydrine ether prepared according to Example 6, in the form of 0.2—0.5 mm grains, were immersed into 500 ml of ethanol and heated under stirring to the boiling temperature. Then 494 g of m - phenylene diamine were added and the suspension was boiled under reflux for 35 hours. By sucking off, washing subsequently with methanol, 1% hydrochlorid acid, 1% sodium lye and water, an aminated copolymer containing 9.92% of nitrogen was obtained. Similar result was achieved by using m - toluylene diamine as aminating agent.

#### EXAMPLE 8

100 g of polymeric macroporous chlorhydrine ether with 20% of the cross-linking agent and 18.2% of chlorine, prepared according to Example 6, were heated with 1000 ml of a 30% aqueous trimethylamine solution for 8 hours at 60°C. The aminated copolymer was then washed with 5% hydrochlorid acid and dried at 20°C. Its nitrogen content as 3.94%. The amination can be facilitated by adding an aromatic hydrocarbon to the aqueous amine solution. So e.g. if an amination of a macroporous polymeric chlorhydrine ether, containing 20% of a cross-linking agent and 15.5% of chlorine with an aqueous dimethylamine solution for 8 hours at 60°C resulted in a nitrogen content of 1.82% in the product, in a parallel experiment at equal conditions except admixture of toluene the nitrogen content in the product amounted to 3.5%.

#### WHAT WE CLAIM IS:—

1. Method for manufacture of a macroporous copolymer comprising copolymerization of a hydrophilic mono - olefinic monomer selected from the group consisting of methacrylates and acrylates of alkyleneglycols, glycerol and other hydrophilic polyols, with a cross-linking agent soluble in the monomeric mixture, in presence of a polymerization initiator and a substantially inert liquid which dissolves the monomers but neither dissolves nor swells the cross-linked copolymer thus formed.

2. Method as claimed in claim 1 where-

in an aromatic hydrocarbon liquid at ambient temperature is used as inert liquid.

3. Method as claimed in claim 1, wherein a small amount of a liquid capable of swelling the cross-linked polymer is added.

5. 4. Method as claimed in claim 1, characterized by carrying out the copolymerization in a tube or in another supporting structure in which the macroporous polymer is to be used.

5. A method as claimed in claim 1, substantially as described with reference to any one of Examples 1 to 5.

For the Applicants,  
MATTHEWS, HADDAN & CO.,  
Chartered Patent Agents,  
31/32 Bedford Street,  
Strand,  
London, W.C.2.

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